Virtual Research Presentation Conference

ADDITIVE DESIGN & DEVELOPMENT OF 3D PRINTED MAGNETICALLY SHIELDED HALL THRUSTERS

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Program: Topic

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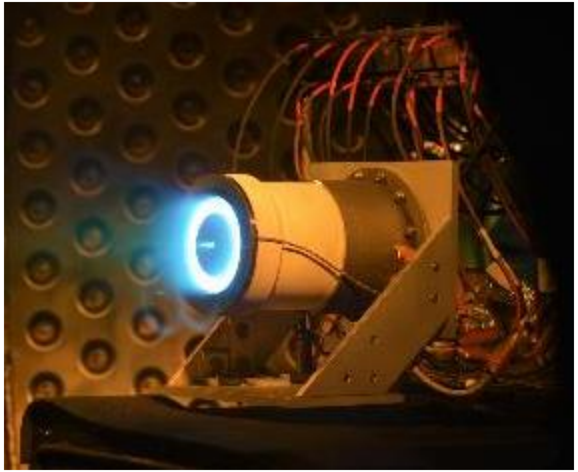
Tutorial Introduction

Abstract

Magnetic alloys are commonly used in aerospace applications, but until recently these alloys have not experienced the renaissance of additive manufacturing that structural metals have. In this project the investigators intend to demonstrate the usefulness of additive manufacturing applied to the fabrication of the soft magnetic FeCo-2V alloy, Hiperco50, used in magnetically shielded Hall thrusters. The application of two laser powder printing processes are discussed, as is post processing including machining and heat treating. The potential for metallurgical gradients from the soft magnetic alloy to a more structural material is also discussed.



Conversano et al., "Development and Initial Performance Testing of a Low-Power Magnetically Shielded Hall Thruster with an Internally-Mounted Hollow Cathode", Proceedings of the 35th International Electric Propulsion Conference, Georgia Institute of Technology, 2017

Problem Description

a) FeCo alloys are traditionally difficult and time consuming to machine. Through a CIF project, the team demonstrated the proof of concept that Hiperco could be 3D printed and that, with the proper heat treatment, equivalent magnetic properties could be realized. The authors proposed to demonstrate 3D printing Hiperco as a means to rapidly prototype magnetically shielded Hall thrusters, increase the design space for said thrusters by enabling monolithic constructions and the potential for integrated thermal management and/or structural optimization for mass reduction, with reduced cost and fabrication schedule.

b) The Magnetically Shielded Miniaturized (MaSMi) Hall thruster was selected for the baseline design. Fabrication of the magnetic shielding components in this system takes ~2 months. The goal of this project is to demonstrate a 75% reduction in the time required to fabricate these components and associated cost benefits, while maintaining performance. Additionally, in larger systems, other materials are incorporated using bolted joints while metallurgical gradients are enabled by additive manufacturing (AM) allowing monolithic constructions.

c) Hall thrusters are an important element in JPL’s propulsion technology portfolio and this technology could be considered for proposed missions using Solar Electric Propulsion such as a Ceres lander, Lunar Orbiting Platform, and Mars orbiters. The proposed materials technology will enable reduced cost and schedule for fabrication of these thrusters while enabling unique thruster designs only manufacturable by 3D printing.

Methodology

a) Leverage advances made in 3D printing Hiperco® under CIF and JPL's new 3D printing capability in directed energy deposition (DED) and laser powder bed fusion (L-PBF) to design and fabricate the Hiperco®50 components of a low-power MaSMi (Magnetically Shielded Miniature) Hall Thruster.
   - a) Develop the design requirements and process flow for DED (year 1) and L-PBF (year 2)
   - b) 3D-printed variant of the latest generation MaSMi thruster Optimize 3D printing parameters by building test coupons
   - c) Fabricate the components to near-net shape, finish machine and heat treat
   - d) Assemble and functionally test for comparison to traditionally manufactured equivalent MaSMi thruster
   - e) Characterize the microstructure and materials properties at the different stages of fabrication.
   - f) Track cost and schedule associated with the fabrication of the thruster for comparison with the state-of-the-art (SOA).
   - g) Fabricate gradient iron/Hiperco coupon, heat treat, and characterize

b) Technical hurdles include establishing design parameters for optimal near-net shape fabrication; build parameters to optimize for as-printed density and microstructure development; thermal processing of gradient to achieve optimum properties (structural and magnetic)

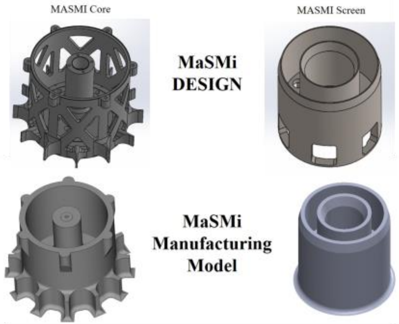
c) The innovation or advancement in this work is the understanding of the relationship between the laser AM processes and post-processing heat treatments to achieve the desired magnetic properties. The thermal history developed in the component during AM fabrication seeds the microstructure development during subsequent heat treatment and the resulting magnetic properties.

Results

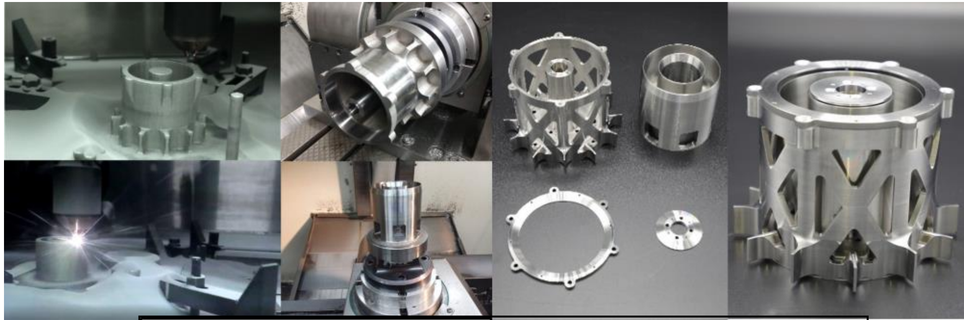
a) Directed Energy Deposition (DED): In the previous year the four (4) Hiperco50 thruster components (core, screen, and pole pieces) were successfully printed using DED, machined, and heat treated for testing

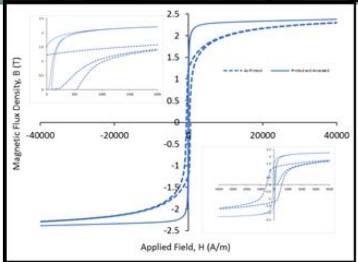
- a) 100 hours of AM printing time over two weeks on two build plates followed by ~100 hours of total machining time completed in parallel over one week and 1 week to complete heat treating
  - a) 50% schedule reduction compared to baseline, but no observed component cost reduction
- b) Magnetic field mapping of components showed equivalent performance to wrought

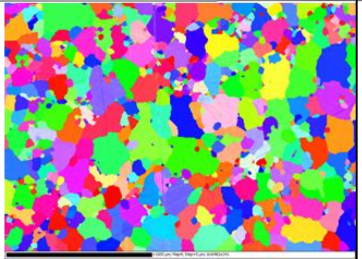
JPL's RPM 222 Directed Energy Deposition (DED) System



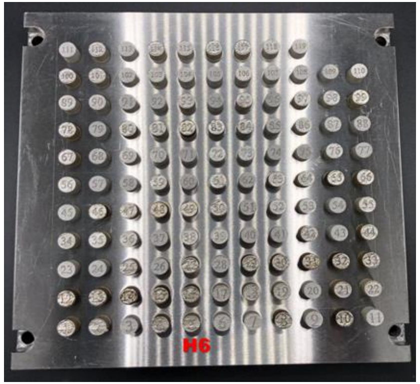
MaSMi core and screen components and manufacturing models used for printing







Results



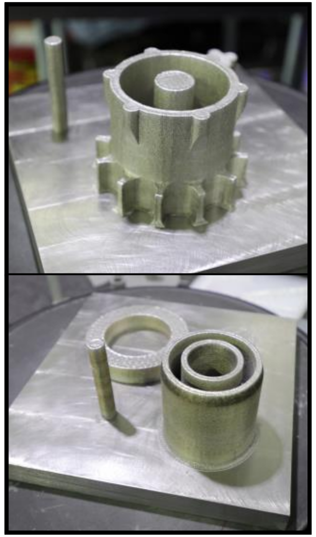
b) Laser Powder Bed Fusion (L-PBF): Due to improved resolution in L-PBF the manufacturing model could be reduced by more than 30% for all 4 parts; process developed out of house due to COVID-19 affecting equipment availability

   a) Process parameters developed for laser power, laser speed, and spacing (or hatch) with vendor

   b) 40 hours of AM printing time on one build plate followed by ~100 hours of total machining time completed in parallel over one week and 1 week to complete heat treating

      a) 62.5% schedule reduction from the baseline, one week short of the 75% goal, but no observed component cost reduction

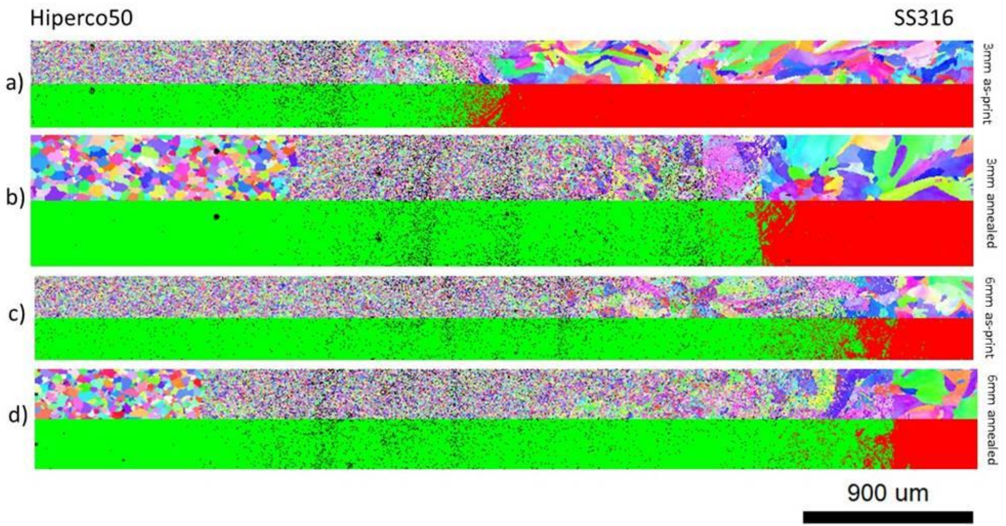
      b) Setup (CNC programming) has a greater impact on machining time. Efficiencies could be improved machining multiples of the same part using a single setup. Use of recycled powder could further reduce cost.

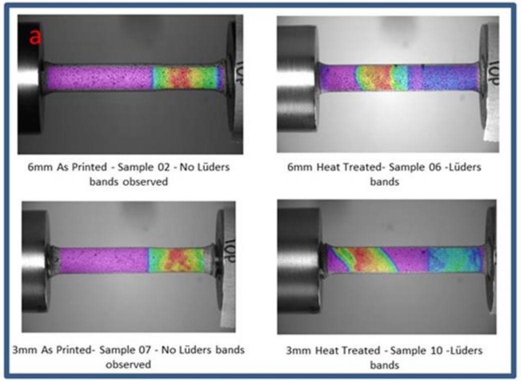


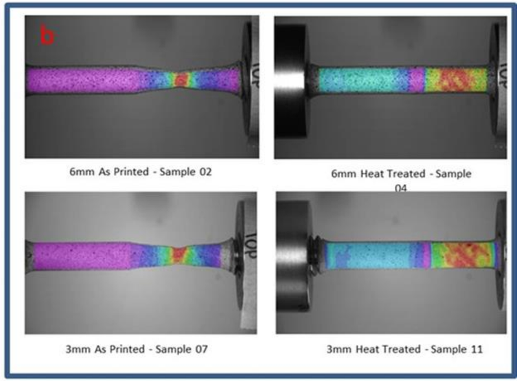
Results

c) Compositional gradients

- a) Successful fabrication of Hiperco50 to 316 stainless steel (SS316) gradients of varying gradient lengths fabricated using DED
- b) Gradients characterized using scanning electron microscopy (SEM) with electron back scatter diffraction (EBSD)
    - a) Distinct microstructural regions are observed in the gradient.
- c) Mechanical testing performed by Sandia National Lab included digital image correlation (DIC)
    - a) Distinct mechanical behavior between the as-printed and heat-treated samples.
    - b) As-printed condition failure occurred in the pure SS316 portion of the gauge area. Hiperco50 has a disordered BCC structure in this state
    - c) Heat-treated condition failure occurred in the pure Hiperco50 portion of the gauge area. Hiperco50 has an ordered BCC structure in this state.
    - d) Failure never occurred in the fine grain gradient region.







Results

d) Significance

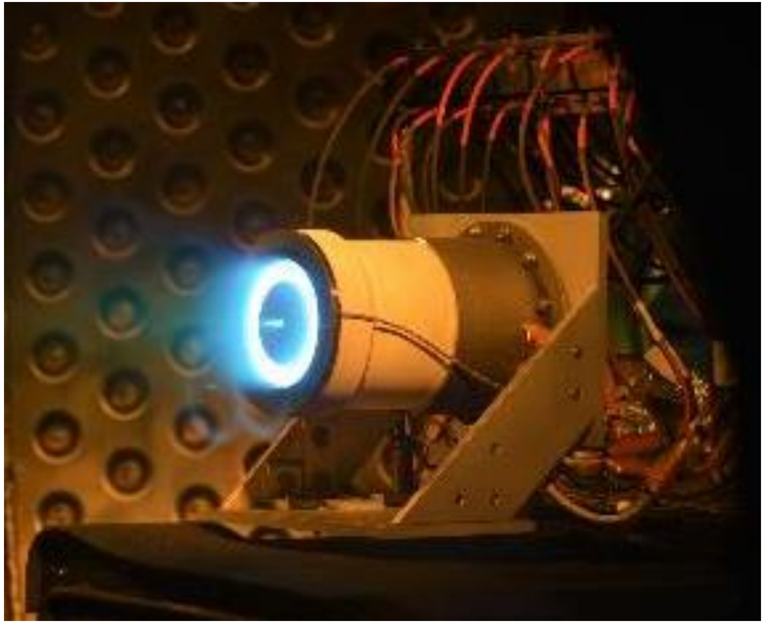
It was demonstrated that MaSMi Hall thruster scale components can be fabricated by AM and magnetic field mapping of the DED fabricated components demonstrated equivalent performance to wrought. Both DED and L-PBF can significantly impact the fabrication schedule and opens the design space for potentially integrating thermal management technology. A ferrous metal gradient with Hiperco was demonstrated with the potential for eliminating some bolted joints and reducing part count.

e) Next steps

Magnetic field mapping of L-PBF fabricated components to confirm magnetic behavior relative to wrought.

Functional test of AM fabricated components to demonstrate functional capability.

Modeling of larger Hall thrusters for potential integration of thermal control.



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Publications and References

There have not been any publication as result of this work at this time.

This research did result in U.S. Patent application 20190366435 published December 5, 2019.